

An Environmental Kuznets Curve Analysis of
U.S. State-Level Carbon Dioxide Emissions¹

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Abstract

Most environmental Kuznets curve (EKC) theories do not apply to carbon dioxide – an unregulated, invisible, odorless gas with no direct human health effects. This analysis addresses the hypothesis that the income-CO₂ relationship reflects changes in the composition of an economy as it develops and the associated role of emissions-intensive trade. To test this hypothesis, I use a novel data set of 1960-1999 state-level carbon dioxide (CO₂) emissions to estimate pre-trade (production-based) CO₂ EKCs and post-trade (consumption-based) CO₂ EKCs. As the first EKC analysis of CO₂ emissions in the U.S. states, I find that consumption-based EKCs peak at significantly higher incomes than production-based EKCs, suggesting that emissions-intensive trade drives at least in part the income-emissions relationship. I have also investigated the robustness of the estimated income-CO₂ relationship through a variety of specifications. Estimated EKCs appear to vary by state, and the estimated income-emissions relationships could be spurious for some states with nonstationary income and emissions data. Finally, I find that cold winters, warm summers, and historic coal endowments are positively associated with states' CO₂ emissions.

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1. Introduction

Empirical researchers have characterized the relationship between economic development and environmental pollution with the environmental Kuznets curve (EKC) – pollution follows an inverted-U shape with respect to per capita income. The application of EKC analyses to greenhouse gas emissions, such as carbon dioxide (CO₂), has raised several important questions. First, some empirical studies have estimated an inverted-U shape of per capita CO₂ emissions with respect to per capita income, but with a peak in this function occurring well outside the range of incomes in the studies' samples. Since these studies often rely on restrictive regression specifications (i.e., quadratic income), these results do not support unequivocally an inverted-U for per capita CO₂ emissions. Moreover, recent empirical analyses have challenged the robustness of estimated environmental Kuznets curve relationships (Harbaugh et al. 2002, Millimet et al. 2003, Perman and Stern 2003).

Second, some studies have suggested that the inverted-U reflects an economy's changing structure as it develops: economies are characterized by agriculture at low incomes, then move to more emissions-intensive manufacturing at middle incomes, and then transition to less emissions-intensive services at high incomes. Trade in emissions-intensive goods facilitates this specialization. The downward slope of the inverted-U estimated for higher incomes may reflect the combination of a transition from manufacturing to services and an increase in imports of emissions-intensive manufactured goods. Since *all* economies cannot import emissions-intensive goods, failing to account for these trade effects could bias downward long-term emissions forecasts.

This paper addresses these two questions and makes several additional contributions to the environmental Kuznets curve literature and related policy debates. First, by using a novel data set constructed by the author of state-level CO₂ emissions for the 1960-1999 period, this paper presents the first environmental Kuznets curve analysis for CO₂ emissions in the U.S. states. Second, by focusing on

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the U.S. states – a set of economies that have achieved advanced stages of economic development – this analysis provides better evidence of whether per capita emissions actually do fall at high income levels. Third, with a states dataset, the empirical analysis investigates explicitly the effects of emissions-intensive trade on the income-CO₂ relationship. Fourth, this research evaluates other determinants of CO₂ emissions, such as energy endowments and the variation in winter and summer climates across the country. Finally, by employing a variety of econometric methods, this paper assesses the robustness of the income-emissions relationship.

The empirical results based on standard EKC specifications illustrate that per capita CO₂ emissions may follow an inverted-U pattern with respect to per capita income for the U.S. states over the 1960-1999 period. The estimated peak in the environmental Kuznets curve does occur at incomes that fall within the sample range. The estimated EKCs, however, are sensitive to a number of modifications to the analysis. First, as an explicit test of the effect of trade in emissions-intensive goods, I have estimated pre- and post-trade environmental Kuznet curve regressions. I find that consumption-based CO₂ per capita (post-trade) EKCs have peaks at much higher incomes than the standard (production-based or pre-trade) CO₂ per capita measure. Further, consumption-based CO₂ emissions appear to remain much higher at high incomes than production-based CO₂ based on more flexible regression specifications. This suggests that individuals in high income states don't consume less carbon-intensive goods than those in lower income states, but that they consume more imported carbon-intensive goods and lower income states may be net exporters of carbon-intensive goods. Second, I assess whether the income-emissions relationship is the same across the states. Tests of heterogeneous slopes models show that this relationship varies across the states. Third, an evaluation of the time series properties of the state-level data suggests that some estimated relationships could be spurious and that less than one in five states follow an inverted-U environmental Kuznets curve for which one could reject the possibility of a spurious relationship. Finally, I find that states' cold winter and warm summer weather and historic coal endowments are positively associated with states' per capita carbon dioxide emissions.

By characterizing the income-CO₂ relationship for the U.S. states, this analysis can also help inform our understanding of greenhouse gas emissions in an international context. First, illustrating the economic dynamics of per capita CO₂ for high-income states provide evidence of what may occur for countries as they achieve advanced stages of development. Second, the potential role of trade in emissions-intensive goods (e.g., electricity) in the income-CO₂ relationship may be valuable for other regions of the world that may share similar characteristics to the U.S. states. For example, the European Union, with converging incomes, policies, and institutions and substantial cross-border trade in emissions-intensive goods and energy may follow similar production- and consumption-based CO₂ trends as the U.S. states. Third, if trade in emissions-intensive goods is as important in the international context as for the U.S. states, then this work suggests that studies that attempt to forecast carbon dioxide emissions may produce biased results without attempts to correct for trade.

The next section briefly reviews several key hypotheses of the environmental Kuznets curve literature as it relates to greenhouse gas emissions. The third section provides an overview of the data used in this paper, including the novel state-level carbon dioxide emissions dataset constructed by the author. The fourth section describes the empirical methods and presents the results of the analysis. The final section concludes.

2. Hypotheses of Environmental Kuznets Curve Related to Greenhouse Gas Emissions

A variety of theories have been posited to motivate the empirical work of the environmental Kuznets curve (see Selden and Song 1994, Arrow et al. 1995, Stern 1998). First, environmental quality may be income elastic. As individuals enjoy greater incomes, they demand better environmental quality either through markets or regulatory policies. Second, and related to this first point, is the increasing role of democracy with economic development. Since emissions of many environmental pollutants reflect missing markets, government institutions are necessary to address them. More responsive democracy may be necessary in order to translate individual demand for environmental quality into policies that restrict pollution. In contrast to air or water pollution, which can have immediate, identifiable local health

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effects, carbon dioxide emissions are locally innocuous and only impact the global environment over the long term (which may explain the lack of historical regulations or taxes on carbon dioxide emissions). Moreover, *per capita* carbon dioxide emissions have no local impacts and reflect at best an indirect measure of the impact on the global environment. It is not clear that either of these phenomena would explain the per capita carbon dioxide environmental Kuznets curve.²

Third, the inverted-U shape may reflect changes in production associated with an economy's stage of development and a wedge between the emissions-intensity of production and the intensity of consumption (Arrow et al. 1995, Rothman 1998). For example, a decrease in pollution in one economy may simply represent a shift in the polluting production activity to another economy, which would then experience an increase in pollution. This second economy would then export pollution-intensive goods to the first economy. This could follow the development path from agriculture (low income) to heavy industry (middle income) to services (high income). Since agriculture tends to be less energy-intensive (carbon-intensive) than heavy industry, which is also more energy-intensive (carbon-intensive) than services, this development path could result in an environmental Kuznets curve for carbon dioxide. Note, however, that the inverted-U would only be temporary, since every economy cannot specialize in services and export its heavy industry to other economies.

While a variety of theories may explain the shape of the environmental Kuznets curve for many local air pollutants, only the development-induced changes in production coupled with trade story seems plausible for carbon dioxide. An empirical test of this theory could attempt to discern the production of carbon-based goods from the consumption of these goods. Modifying measures of carbon dioxide emissions to reflect the location of consumption and comparing these with the standard measures that reflect location of production could allow for an assessment of whether the inverted-U shape of per capita

² Andreoni and Levinson (2001) also illustrate how increasing returns to pollution abatement could yield an inverted-U income-pollution relationship. Since no state or federal regulatory authorities implemented policies to control carbon dioxide emissions over the 1960-1999 period, this hypothesis is probably not relevant to CO₂ emissions.

emissions with income simply reflects shifts in production or substantial changes in the carbon-intensity of consumption at higher income levels.

Several papers have attempted to test for this production-location hypothesis by simply expanding the set of regressors to include measures of trade and manufacturing intensity. For example, Harbaugh et al. (2002), in an analysis of sulfur dioxide concentrations and other pollutants, included a measure of trade intensity, which nearly doubles the income at which the estimated environmental Kuznets curve peaks. Suri and Chapman (1998) investigated energy use per capita and compared EKC regressions with and without a number of such controls: the ratio of manufacturing exports to domestic manufactured production, the ratio of manufacturing imports to domestic manufactured production, and the ratio of total manufacturing value added to GDP. For the Suri and Chapman analysis without these controls for trade, the estimated EKC peaked at about \$55,000 (1985\$). Including these additional variables resulted in a peak of nearly \$144,000. In contrast, Cole (2003) included measures of trade intensity in EKC regressions of SO₂, NO_x, and CO₂, and found that these tended to have a minor impact on the estimated peaks in these environmental Kuznets curves. Frankel and Rose (2002) have also investigated the role of trade and economic growth on environmental quality, and they find in-sample environmental Kuznets curve peaks for SO₂ and NO_x concentrations when accounting for the trade share of GDP. Interestingly, Frankel and Rose estimate an always-increasing environmental Kuznets curve for CO₂ per capita when controlling for trade.³

While some papers suggest that accounting for trade generally may increase the income at which environmental Kuznets curves peak, caution should be exercised when considering this approach. Some researchers have noted previously that as a reduced-form framework, EKC regressions should not include regressors that may be endogenous to the income variables, or the economic growth process more generally (Holtz-Eakin and Selden 1995, Heil and Selden 2001). It may not be appropriate to include the trade share of output or the economy's manufacturing intensity as regressors and then estimate the income

³ Refer to Antweiler et al. (2001) for a more detailed evaluation of the determinants of sulfur dioxide emissions that focuses on disaggregating the impacts of trade on the environment through scale, technique, and composition effects.

at the EKC peak from the regression's income variables holding everything else, including trade and manufacturing variables, constant (as is typically done in the literature). Since manufacturing intensity and trade intensity are likely to be systematically related to the economic growth process, constructing the EKC peak only from the income variables would result in a biased estimate because it omits the information in the manufacturing and trade variables that may explain in part the relationship between development and emissions. The approach in this paper to modify the measure of emissions directly to reflect trade aims to circumvent this potential bias.

3. Emissions and Income Data

3.1 Carbon Dioxide Emissions Data

Since long-term CO₂ emissions data sets do not exist for the U.S. states, I have constructed state-level emissions estimates based on fossil fuel combustion data (refer to Lutter 2000 and Marland et al. 2003 for similar applications of this approach).⁴ The Energy Information Administration (2001b) has compiled state-level energy consumption by fuel type and sector for the 1960-1999 period. I converted energy consumption by sector-specific fuel type to CO₂ emissions using U.S. emissions factors provided in EIA (2001a; Appendix B).

As one test of the plausibility of this construction, I aggregated these state-level CO₂ emissions values to yield annual national estimates and compared these to the Marland et al. estimates for U.S. emissions. Over the 1960-1999 period, my constructed U.S. values differ on average 1.7 percent from the Marland et al. estimates (1.0 percent standard deviation). The maximum annual differential between the data sets is 3.8 percent. A comparison with EIA (2001a) CO₂ emissions estimates for the United States over this time period yields very similar results. While some states likely have measurement error in excess of 1.7 percent, this comparison illustrates the plausibility of the energy-based construction of state carbon dioxide emissions developed for this paper.

⁴ Carbon dioxide emissions are expressed in terms of tons of carbon in this paper.

These carbon dioxide estimates reflect all within-state fossil fuel combustion emissions. They represent emissions associated with producing all goods and services in a given state, so we can also denote them *production*-based CO₂ emissions. In the presence of interstate trade, the emissions intensity of a state's production may differ from the intensity of this state's consumption. To explore this distinction, a second carbon dioxide emissions data set was constructed to account for interstate electricity trade. To modify the carbon dioxide emissions data set, I first calculated the annual average carbon-intensity of each state's electricity sector. For a state that is a net exporter of electricity in a given year, the carbon emissions associated with the exported electricity (reflecting the state's average electricity carbon intensity) are deducted from that state's total emissions for that year. For a net importer, that state's emissions are augmented based on the average carbon intensity of electricity imports.⁵ Since this modified measure reflects post-trade emissions and attempts to approximate for *consumption*-based emissions, as opposed to the production-based or standard measure of emissions, I refer to it as consumption-based CO₂ throughout this analysis.⁶

3.2 State Income and Population Data

The income variables used in the statistical analyses represent state personal income data provided by the Bureau of Economic Analysis (2000).⁷ These data have been used in a variety of economic analyses, including papers on economic growth and the environmental Kuznets curve (e.g., Barro and Sala-i-Martin 1992, List and Gallet 1999, and Millimet et al. 2003). The Bureau of Economic Analysis also provides annual state-level population estimates. These population values were used to construct all per capita estimates.

⁵ While the carbon-intensity of the marginal power source for electricity would be preferable, it is difficult to determine what constitutes the marginal source in each state. Simply assuming the fuel type of the most recent plant(s) to come on-line may be misleading since this approach may characterize hydropower dams or nuclear power plants as the marginal fuel source. For example, lack of economic water resources may make replication of a dam within a state difficult. The long construction and licensing process for nuclear power plants (and the fact that zero nuclear facility license applications were submitted in the second half of my sample period) complicates consideration of nuclear power as a marginal power source.

⁶ Ideally, a complete consumption-based measure of carbon dioxide would also reflect the emissions intensity in all traded goods and services. Unfortunately, such interstate trade data are not collected.

⁷ These values were converted to 1999 dollars based on the national CPI-Urban deflator (CEA 2001, Table B60).

3.3 Climate Data

Previous research has shown that weather fluctuations can cause short-term shocks to energy demand that influence carbon dioxide emissions (Considine 2000, EIA 2001a). The National Oceanic and Atmospheric Administration (NOAA) has developed so-called “heating degree-days” (HDD) and “cooling degree-days” (CDD) metrics to characterize the effects of high summer temperatures and low winter temperatures on energy demand. Annual data for state heating and cooling degree-days were compiled from Heim et al. (1993a, 1993b) and NOAA (multiple dates).

3.4 Energy Endowment Data

The energy endowment variable reflects a state’s coal endowment. To focus on the persistent effects of historic coal production on the industrial composition and associated emissions in a state, I focus on lagged coal production (ten-year lag). The historic coal production data reflect state-level production of all types of coal. These data were compiled and provided by the Energy Information Administration (Bonskowski 2002), and measure coal in thousands of short tons.

3.5 Descriptive Statistics

The variables used in the regression analyses presented below are summarized in Table 1. The state-level data for the 1960-1999 period reveal substantial variation in the per capita carbon dioxide emissions data and per capita income data. State average per capita carbon dioxide emissions is about 5.75 tons. Within a given year the ratio of maximum to minimum per capita carbon dioxide varies from about four in the 1960s to the high teens over the past several decades.⁸ This variation in per capita emissions is not too dissimilar from the variation evident in international data sets: the ratio of U.S. per capita emissions to India per capita emissions in 1999 is almost identical to the ratio of the maximum to

⁸ The increasing dispersion in per capita carbon dioxide emissions over time is evident for the entire sample of states, and not just the outlying annual minimums and maximums in the sample. Refer to Aldy (2004) for further details.

the minimum per capita emissions among the states in that year. Per capita incomes vary by about a factor of two in any given year and by a factor of more than five over the entire 40-year sample. Incomes at the beginning of the sample ranged between about \$7,000 and \$16,500, about on par with current middle-income developing countries (e.g., Venezuela or Brazil) and lower income OECD countries (e.g., the Czech Republic or South Korea), in purchasing power parity terms.

4. Methods and Results

4.1 Estimation Strategy

To estimate the environmental Kuznets curve for state-level carbon dioxide emissions per capita, I employed four econometric approaches with a panel of 48 states over the 1960-1999 period.⁹ The general regression specification takes the following form:

$$\ln(CO_{2it}) = F[\ln y_{it}; \beta] + \gamma X_{it} + \alpha_i + \tau_t + \varepsilon_{it}$$

where CO_{2it} represents per capita carbon dioxide emissions in state i in year t , y_{it} represents per capita income, X represents the vector of other explanatory variables (lnCDD, lnHDD, and coal production), β and γ are vectors of parameters to be estimated, α_i and τ_t are state and year fixed effects, ε_{it} is the error term which is characterized by a strict exogeneity assumption:

$$E[\varepsilon_{it} \mid \{CO_{2is}, Z_{is}\}_{s=1960}^{1999}] = 0$$

and Z_{is} represents the vector of all regressors.¹⁰

⁹ Alaska and Hawaii have been omitted from this analysis because cooling degree day and heating degree day data are not available for these states.

¹⁰ F-tests of the inclusion of state and year fixed effects for a variety of specifications all reject the null hypothesis that the coefficient estimates of these effects equal zero.

In the first set of regressions, the income function is specified as a quadratic, following Grossman and Krueger (1995), Holtz-Eakin and Selden (1995), and Heil and Selden (2001). These specifications were estimated by ordinary least squares (OLS) and a feasible generalized least squares (FGLS) approach that corrects for cross-sectional heteroskedasticity and incorporates a one-lag autoregressive error structure.¹¹ For the OLS regressions, I report both robust standard errors and standard errors corrected for within-group heteroskedasticity (the errors have been “clustered” by state). The robust standard errors correct for cross-sectional heteroskedasticity, but assume independence in the residuals in the time series dimension, while the clustered standard errors allow for state-specific arbitrary serial correlation but assume independence across states.

In the second set of regressions, I characterize income by a cubic spline function, a more flexible variant of the piecewise linear spline approach used in Schmalensee et al. (1998). The cubic spline ensures that the estimated environmental Kuznets curve is smooth (twice everywhere differentiable) by fitting cubic functions in-between analyst-chosen points or knots in the data. For example, one could choose nine knots in the data, one at each decile in the income distribution, and fit cubic functions specific to each decile but constrained to be smooth at every knot. I experimented with a variety of specifications, including two to as many as eleven knots in the cubic spline function. The results presented below are robust to setting the distance between knots based on quantiles of the data or based on an equal inter-knot distance rule.

Third, I have made the regression specification more flexible by allowing the slope parameters (β 's) to vary by state, following List and Gallet's (1999) environmental Kuznets curve analysis of state NO_x and SO₂ emissions. This approach allows for an explicit test for whether the inverted-U income-emissions shape is common across all economies or whether this relationship is economy-specific. I find evidence of the latter.

¹¹ Breusch-Pagan tests indicate that the residuals are heteroskedastic (test statistics range from 3468 to 3973 for the production-based CO₂ regressions and 1965 to 1993 for the consumption-based CO₂ regressions). Wald tests of the null hypothesis of no serial correlation in the panel yield F-statistics ranging from 107 to 256 for a variety of specifications, recommending rejection of the null.

Fourth, based on the evidence that the EKC shape is state-specific, I conduct analyses on the 48 separate time series. This facilitates an investigation of state-specific relationships and an evaluation of the time series properties of the data. I find that the emissions and income data are stochastically trending, and that these two time series are cointegrated for only nine states. I conduct dynamic ordinary least squares (DOLS; Stock and Watson 1993) for these states and compare the results with state-specific OLS.

The estimation strategy allows for an examination of two important issues typically not addressed in the environmental Kuznets curve literature. First, I have undertaken a number of regressions with a modified measure of per capita carbon dioxide emissions that reflects the effects of trade on emissions. The standard, production-based measure of carbon dioxide emissions may not best characterize the carbon-intensity of a state or region's standard of living. Consider a hypothetical world with two regions: region 1 specializes in carbon-intensive goods, and region 2 specializes in carbon-lean goods. Suppose that region 1 exports its carbon-intensive goods to region 2, and region 2 exports its carbon-lean goods to region 1. This standard approach to estimating carbon dioxide emissions reflects a region's carbon-intensity of production, and region 1 would have higher emissions than region 2, *ceteris paribus*. The carbon-intensity of consumption, however, would vary from the production carbon-intensity because trade allows the import of carbon-intensive goods in region 2 (and the import of carbon-lean goods in region 1). If one assigned carbon dioxide emissions to the region in which the good associated with those emissions is consumed, then estimates of region 1's emissions would fall while region 2's emissions would increase. Modifying the measure of carbon dioxide emissions to reflect electricity trade is a first step towards employing a true consumption-based carbon dioxide measure. The analyses with this modified measure can serve to illustrate whether the failure to account for trade yields a distinctly different emissions-income relationship and test for the production-shifting hypothesis of the environmental Kuznets curve.

Second, I have included a number of control variables in addition to per capita income that would reasonably be expected to influence per capita carbon dioxide emissions. This analysis can quantitatively

assess questions such as: Do warm weather regions have lower per capita emissions than cold weather regions? Do historical energy endowments influence current per capita emissions? To address these questions, I have included the following variables in a subset of the regressions reported below: annual measures of weather-related heating and cooling demand and lagged (10-year) coal production by state. Colder winter states and hotter summer states would be expected to have higher per capita emissions resulting from greater heating demand (winter) and cooling demand (summer). Historic energy endowments would be expected to influence per capita emissions by a combination of high transportation costs and geographic specialization. In the former case, a state may exploit its local energy resources because the high cost of shipping fuels or transmitting electricity makes it uneconomic to do otherwise. In the latter case, even the decline in transportation costs over time may not substantially alter a region's fuel mix since years of capital investments have already been made geared towards that region's historic fuel mix (see Krugman 1991). The coal endowment variable would be expected to be positively associated with per capita emissions.

4.2 Regression Results

4.2.1 Quadratic Income Specifications

The results for the quadratic income specifications with the standard (production-based) carbon dioxide per capita emissions measure as the dependent variable are provided in Table 2, Columns (1)-(4). All specifications reveal the typical inverted-U shape in income – the linear term is positive while the squared term is negative. The income variables in all specifications are statistically significant at the 1 percent level. In the OLS specifications, all of the additional control variables have the expected signs, although the weather variables are marginally statistically significant at best. In the FGLS specifications, all explanatory variables have their expected signs and all are statistically significant at the 1 percent level.

To test whether the limited set of control variables (income, state effects, and year effects) associated with the typical environmental Kuznets curve specification would be preferred, I have

conducted F-tests of the hypothesis that the X vector variables equal zero: $\ln(\text{CDD})$, $\ln(\text{HDD})$, and lagged coal production. The F-statistic for the comparison of the specifications (Table 2, columns 1 and 2) is 42. Including these additional controls have little impact, however, on the estimated peak in the environmental Kuznets curve. As the bottom row of Table 2 illustrates, the incomes associated with the maximum of the EKC are fairly similar between specifications that only vary in terms of the inclusion of the X vector of variables.

To place some of these estimated coefficients in context, consider their implications for expected per capita emissions across the states based on their 1999 values.¹² North Dakota, with the most heating degree-days in 1999, would have approximately 1.2 tons per capita higher emissions than Florida, with the fewest heating degree-days, *ceteris paribus*. The variation in emissions associated with cooling degree days is negligible. Wyoming, with the most coal production in 1989 (the lagged value for 1999), would be expected to have about 2 tons per capita more emissions than states that do not produce coal.¹³

Table 2, columns (5)-(8) present the regression results for the quadratic income specifications with the consumption-based carbon dioxide emissions per capita dependent variable. Similar to the results with the production-based carbon dioxide variable, these specifications all reveal an inverted-U in income, and all income variables are statistically significant at the 1 percent level. In the OLS specifications, all explanatory variables have their expected signs and are statistically significant at the 1 percent level, with the exception of the weather variables.¹⁴ In the FGLS specifications, all explanatory variables have their expected signs and are statistically significant at the 1 percent level.

The per capita incomes associated with the environmental Kuznets curve peaks are also higher for the consumption-based carbon dioxide emissions specifications than for the standard carbon dioxide emissions specifications. This indicates that higher income states may experience a decline in per capita

¹² All comparisons are based on the coefficient estimates presented in Table 2, column 2 (OLS, full set of control variables).

¹³ Refer to Neumayer (2002) for a cross-country comparison of similar non-income determinants of carbon dioxide emissions.

¹⁴ F-tests regarding the inclusion of the X vector of variables were also conducted for the consumption-based specifications. Based on an F-statistic of 37, I reject the null hypothesis that the X vector coefficients are equal to zero.

carbon dioxide emissions, not because individuals consume less carbon-based goods in those states than before, but because they consume carbon-based goods (in this case, electricity) produced in lower income states. These differences in the income levels associated with EKC peaks between the two specifications are not inconsequential. The per capita incomes associated with the peak of the consumption-based carbon dioxide emissions EKC range from 28 to 48 percent higher than the incomes associated with the production-based carbon dioxide emissions specification.

The differences between the production-based and consumption-based carbon dioxide environmental Kuznets curves are statistically significant. I undertook bivariate least squares regressions in which the dependent variable vector includes production- and consumption-based CO₂ per capita and replicated the results presented in columns 1, 2, 5, and 6 of Table 2. Table 3 shows the results of two F-tests applied to the four specifications. These tests evaluate two hypotheses:

$$\text{Equality of Parameter Estimates: } H_0^1 : \beta_k^{prod} = \beta_k^{cons} \text{ for } k=1, 2, \text{ and}$$

$$\text{Equality of Estimated EKC Peaks: } H_0^2 : \exp\left[-\frac{\beta_1^{prod}}{2\beta_2^{prod}}\right] = \exp\left[-\frac{\beta_1^{cons}}{2\beta_2^{cons}}\right].$$

With F-statistics of 87 and 113 for the first hypothesis and 40 and 48 for the second hypothesis, these results strongly recommend rejecting the null hypotheses. The differences in the magnitudes of the estimated production- and consumption-based CO₂ EKC peaks are economically and statistically significant. Employing the standard, production-based carbon dioxide environmental Kuznets curve for long-term emissions forecasts could result in a substantially different forecast for the U.S. states than using the consumption-based curve since per capita emissions would continue to increase for a longer period of time with the latter function.¹⁵

4.2.2 Cubic Spline Income Specifications

¹⁵ Note again that this consumption-based measure of carbon dioxide emissions only reflects interstate electricity trade. Accounting for interstate trade in other goods and services and for international trade may well affect the estimated consumption-based environmental Kuznets curve.

As an alternative to quadratic income specifications, a cubic spline function of income can also characterize the emissions-income relationship. Employing a cubic spline specification allows for a second approach to investigate the potential effects of emissions-intensive trade on estimation of the carbon dioxide per capita environmental Kuznets curve and to begin assessing the robustness of the EKC estimates. As Schmalensee et al. (1998) note, a spline specification is more flexible than power functions and may better describe the EKC relationship. I have conducted a series of OLS regressions with the cubic spline function divided into as few as 2 and as many as 11 knots for both the production- and consumption-based measures of emissions, and including state and year fixed effects.¹⁶ Based on F-tests evaluated at a 5 percent significance level, I could reject specifications with fewer than 8 knots for the production-based regressions and those with fewer than 10 knots for the consumption-based regressions. Figure 1 presents the estimated EKCs for the production- and consumption-based measures based on 10-knot cubic spline specifications.¹⁷

The figure shows a striking divergence in the income-emissions relationship between the production- and consumption-based measures at higher incomes. The two relationships track each other quite closely over the \$7,000-\$14,000 range, at which point the consumption-based measure crosses the production-based measure and remains at relatively high levels (between about 5.5 and slightly more than 6.0 tons per person) through the rest of the sample range for income. In contrast, the production-based EKC declines substantially with increasing per capita income. At the maximum income level in the sample (about \$39,000), the production-based EKC has a per capita emissions level (3.1 tons per capita) that is just slightly more than half of its peak (5.7 tons per person, occurring at about \$16,000). The consumption-based EKC however, has a per capita emissions level (5.5 tons per capita) that is about 90 percent of the value associated with its peak (6.1 tons per person, occurring at about \$20,500). While the results from the cubic spline specifications confirm the quadratic income results that emissions peak at

¹⁶ Refer to Millimet et al. (2003) for a recent example of a cubic spline specification in an environmental Kuznets curve analysis of local air pollutants.

¹⁷ For consistency between the two emissions measures, I have presented the estimated EKCs based on the same specification. The production-based 8-knot EKC yields a virtually identical (and statistically indistinguishable) shape as the 10-knot version.

higher incomes with the consumption-based measure, these estimated EKC's also show that per capita emissions decline at a much more gradual rate after peaking on a consumption basis than on a production basis.

4.2.3 Heterogeneous Slopes Specifications

The previous two sets of results, and the vast majority of the empirical EKC literature, assume that all economies follow a common income-emissions relationship. While the typical EKC (panel) regression only allows economies' emissions to vary in terms of level (fixed) effects, following List and Gallet (1999), I have relaxed the assumption of common slope terms (β 's) for all states by allowing these parameters to vary by state. I have conducted regressions with both the production-based CO₂ and consumption-based CO₂ measures specified as functions of state-specific quadratic income, state fixed effects, and year fixed effects. This heterogeneous slopes model provides a third approach both for assessing the hypothesis that emissions-intensive trade affects the estimated EKC and for determining the robustness of the earlier results.

Table 4 presents summary statistics of these two regressions. Most states follow an inverted-U shape for the production-based CO₂ measure, although fewer of the states have such a relationship for consumption-based CO₂ per capita. Forty states have a statistically significant estimated EKC peak (and all estimates fall within their states' respective income range) for standard CO₂ per capita, and 37 states do for consumption-based CO₂ per capita. The mean EKC peak for states with inverted-U emissions-income relationships for the production-based CO₂ measure is comparable to the consumption-based measure, but the median EKC peak income for the consumption-based measure is about 15 percent greater than the median production-based measure.

This more general model that allows for heterogeneity in the slope coefficients yields results that question the typical assumption of common parameter estimates for all states. I evaluated the following two hypotheses:

Equality of Parameter Estimates: $H_0^3 : \beta_{k1} = \beta_{ki}$ for $k=1, 2$, and for all $i = 2, \dots, 48$, and

Equality of Estimated EKC Peaks: $H_0^4 : \exp\left[-\frac{\beta_{11}}{2\beta_{21}}\right] = \exp\left[-\frac{\beta_{1i}}{2\beta_{2i}}\right]$ for all $i = 2, \dots, 48$.

F-tests of the equality of the income parameters reject the hypothesis of a common income-emissions relationship among the states. Likewise, tests of equality of the estimated EKC peaks also recommend rejecting the hypothesis that the states can be characterized by one EKC function (refer to last two rows of Table 4). These results are consistent with the findings of List and Gallet (1999) for SO_2 and NO_x environmental Kuznets curves for the U.S. states. Recent research by Brock and Taylor (2004) provides some insights into economy-specific EKCs. State-specific EKC analyses may be appropriate in light of this finding, which motivates the time series analyses in the next section.

4.2.4 State-Specific Time Series Specifications

State-specific EKC regressions can provide several checks to the preceding analyses. First, every state has income per capita observations on both the upward and downward sloping regions of the emissions-income inverted-U estimated with the production-based carbon dioxide per capita measure in Table 2. If this reduced-form relationship estimated from a panel is robust, it should be evident individually among these states. Second, the analysis with heterogeneous slopes indicates that the relationship may not be identical for all economies. A better understanding of which economies experience such trends in emissions as their incomes grow could further inform the theory that motivates the empirical work. Third, several papers in this literature have questioned the empirical methods that fail to account for possible stochastic trends in emissions and income data (see Perman and Stern 2003, Stern 2004). Focusing on state-specific time series will allow for an explicit investigation of these properties for the state-level data.

Before undertaking state-specific regressions, I conducted several time series tests of the income and emissions data. First, I tested for whether the state-specific income and emissions time series are nonstationary (stochastically trending) with the Elliott et al. (1996) GLS version of the Dickey-Fuller test. As a test with higher power than the augmented Dickey-Fuller test, this GLS version is more likely to reject the null hypothesis of a unit root against the alternative of a stationary distribution when the root is close to but less than one. For only one state do the data suggest rejecting the null of a unit root at the five percent significance level for the income time series, and only four additional states at the ten percent significance level. Likewise, I reject the null for only one state for the carbon emissions time series at the five percent level, and for only two states at the ten percent level. To determine if the data are integrated of order one, I conducted the same tests on the first differences in emissions and incomes. For all but one state, the tests recommend rejecting the null hypothesis of a unit root for the changes. The state-specific income and emissions data appear to be integrated of order one time series. This suggests the need to evaluate for whether the state-specific time series are cointegrated to determine if the reduced-form EKC regression analyses are actually spurious.¹⁸

If the emissions and income time series for a given state share a common stochastic trend (are cointegrated), then regression analysis can still be conducted to estimate consistent parameters on the income variables. Since the cointegration vector is not known, I made a preliminary estimate of the cointegration vector and tested for whether the emissions and the income and income squared variables share a common trend with the Engle-Granger Augmented Dickey-Fuller test (EG-ADF; Engle and Granger 1987). First, I conducted an OLS regression for each state of the natural logarithm of per capita emissions on the natural logarithm of per capita income and the square of the natural logarithm of per capita income. Second, I constructed the predicted residuals from these regressions and test these for a unit root with an augmented Dickey-Fuller test. If the data reject the hypothesis of a unit root, then the estimated cointegrating vector (the parameter estimates on the income variables) yields a stationary

¹⁸ I estimated EKC regressions in first differences, with both the full panel and state-specific time series. Virtually every regression yielded statistically insignificant coefficient estimates for the income variables.

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relationship between the emissions and income variables. Following Stock (1994), I used the Akaike Information Criterion to determine the lag structure of the second stage test of the residuals.

The results of the cointegration tests showed that few states have cointegrated data. Using a 10 percent critical level cutoff, I could reject the hypothesis of a unit autoregressive root for the residual for nine (eleven) of 48 states for the production-based (consumption-based) analyses. Refer to Tables 5 and 6 for the results of the EG-ADF tests. This suggests that the income-emissions relationship estimated through OLS could be spurious for many states, and may also be in a panel context (see Perman and Stern 2003 for similar findings for an international EKC analysis of sulfur dioxide emissions).

To provide consistent estimates of the parameters and their associated standard errors for the states with cointegrated data, I estimated state-specific dynamic ordinary least squares (DOLS) regressions following Stock and Watson (1993):

$$\ln(CO_{2,t}) = \alpha_0 + \beta'Y_t + \sum_{j=-p}^p \delta \Delta Y_{t-j} + \varepsilon_t$$

where Y_t represents the natural logarithm of income per capita and its square, ΔY_{t-j} represents lags, leads, and current values of the changes in the two income variables, p represents the number of lags/leads (assumed to be 2 in this analysis), and β and δ are parameter vectors to be estimated. The t-statistics constructed from DOLS are based on Newey-West standard errors (I have assumed a two-period lag structure). The β parameter vector can be considered the long-run effect of the income variables on the emissions variable (assuming that the income variables are exogenous). I compare these with OLS regressions of the natural logarithm of emissions on a constant, the natural logarithm of income per capita and its square, with Newey-West standard errors assuming a two-period autocorrelation structure. All DOLS regression results are presented, even for states with data that do not reject the null of no cointegration in the EG-ADF tests.

Consider the state-specific OLS results presented in Table 5. Thirty-two states have inverted-U EKC's that have estimated peaks that are statistically different from zero ($p < 0.05$) and within their sample income range. The consumption-based state-specific OLS results in Table 6 show even more evidence of an inverted-U income-emissions relationship: 38 states have statistically significant EKC estimated peaks in their sample income ranges.

While the estimated state-specific EKC peaks are similar for production- and consumption-based carbon dioxide measures for many states, a pattern is evident in these comparisons. States that have tended to be electricity exporters more frequently over the sample period have higher production-based EKC peaks than consumption-based EKC peaks. In contrast, the states that tended to be electricity importers have higher consumption-based EKC peaks than production-based EKC peaks. Both of these findings are consistent with the view that trade in emissions-intensive goods can influence estimated income-emissions relationships.

These results may be interpreted as supportive of the earlier reported regressions, although caution should be exercised because of the stochastic trends characterizing the income and emissions time series for most states. The far right columns in both tables present the DOLS results, with those states with cointegrated data in bold. For the production-based CO₂ results in Table 5, only eight of forty-eight states are characterized by both cointegrated time series and inverted-U income-emissions relationships with statistically significant ($p < 0.05$) estimated peaks. Another nineteen states have an inverted-U shape with a statistically significant in-sample emissions peak from the DOLS specifications, but because of the cointegration tests, one cannot rule out a spurious regression and inconsistent variance estimates. For the consumption-based CO₂ results in Table 6, only seven states are characterized by both cointegrated time series and inverted-U income-emissions relationships with statistically significant ($p < 0.05$) estimated peaks. Another twenty-six states have an inverted-U shape with a statistically significant in-sample emissions peak, but could not be described as having cointegrated data. If the null of no cointegration could be rejected for every state, the evidence from the DOLS models would suggest that no more than

two-thirds of the states have an inverted-U income-emissions relationship in either consumption-based or production-based carbon dioxide emissions.

5. Conclusions

This paper provides the first evaluation of a per capita carbon dioxide emissions environmental Kuznets curve for the U.S. states with a novel data set on CO₂ emissions constructed by the author. By focusing on the role of emissions-intensive trade, this analysis evaluates an important carbon dioxide environmental Kuznets curve hypothesis, but the estimated inverted-U income-emissions relationships did vary across several specifications.

The only theory of the environmental Kuznets curve that appears plausible for per capita carbon dioxide emissions focuses on the shifts in energy-intensive production associated with various stages of economic development. All countries cannot someday converge to a low carbon-intensity, advanced stage of development characterized by specialization in services and imports of carbon-intensive goods from other countries. This certainly questions whether the inverted-U income-emissions shape is permanent or only reflects the presumably temporary variation in economic development across the world. While the previous literature has attempted to address this issue by including broad measures of trade as additional regressors, this paper makes a contribution by explicitly adjusting carbon dioxide emissions based on the emissions intensity of net electricity trade. The empirical evaluation in section 4 provides evidence in support of this theory as the estimated EKC for consumption-based CO₂ have peaks at higher incomes than standard or production-based CO₂ EKCs and the post-peak shapes of these two types of EKCS also appear to diverge.

The empirical work also calls into question the robustness of the inverted-U shape of the per capita carbon dioxide EKC. The consumption-based environmental Kuznets curve appears to have higher peaks and much higher post-peak emissions than production-based EKCs. Tests for common slope parameters suggest that the states do not follow a common income-emissions relationship. The state-specific time series regressions show that some of the estimated reduced-form regressions may be

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spurious, and few states have cointegrated data that yield a statistically significant inverted-U environmental Kuznets curve. The regression results also show that per capita emissions do reflect variations in state climatic conditions as well as the impact of historic energy endowments.

Finally, the empirical work also highlights several issues that merit consideration in subsequent environmental Kuznets curve research. Accounting for a limited amount of trade (in this case, electricity trade) has important implications for the shape of the environmental Kuznets curve. Testing for this effect in international data, perhaps with data on trade in goods and services, could further assess whether the income-emissions relationship derives primarily from shifts in production. Including trade effects (consumption-based measure) casts some doubt whether per capita emissions fall appreciably with income over any part of the sample, despite the advanced stage of development characterizing the data. If this pattern holds for international data, it could have important implications for forecasting long-term carbon dioxide emissions. Finally, the state-specific time series results confirm concerns raised in Perman and Stern (2003) that failure to account for potential stochastic trends in the data may yield misleading results. Continued work applying time series methods to evaluate the robustness of estimated environmental Kuznets curves would be worthwhile.

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Table 1. Summary Statistics of U.S. State-level Data, 1960-1999

Variable	Description	Mean in levels (standard deviation)	Mean in logs (standard deviation)
Carbon Dioxide (CO ₂)	Per capita carbon dioxide emissions from fossil fuel combustion (tons of carbon).	5.74 (3.81)	1.61 (0.49)
Consumption-Based Carbon Dioxide (CO ₂ ^{cons})	Per capita carbon dioxide emissions from fossil fuel combustion corrected for emissions associated with net interstate trade in electricity (tons of carbon).	5.34 (2.34)	1.59 (0.40)
y	Personal income per capita, 1999 dollars.	\$19,571 (\$5,123)	9.85 (0.27)
CDD	Annual cooling degree days.	1051 (758)	6.69 (0.77)
HDD	Annual heating degree days.	5,321 (2,041)	8.48 (0.50)
coal production	State coal production (10-year lag), 1000s short tons.	13,151 (30,403)	8.85 (1.98)

N = 1,920.

Table 2. Regression Results for Quadratic Income Specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Specification	OLS	OLS	FGLS	FGLS	OLS	OLS	FGLS	FGLS
Dependent Variable	ln(CO ₂) Production	ln(CO ₂) Production	ln(CO ₂) Production	ln(CO ₂) Production	ln(CO ₂ ^{cons}) Consumption	ln(CO ₂ ^{cons}) Consumption	ln(CO ₂ ^{cons}) Consumption	ln(CO ₂ ^{cons}) Consumption
ln(y)	15.06 (0.76)* [2.78]*	13.36 (0.77)* [2.78]*	8.34 (0.26)*	8.45 (0.31)*	8.12 (0.66)* [2.38]*	7.14 (0.66)* [2.30]*	6.23 (0.22)*	6.13 (0.16)*
ln(y) ²	-0.78 (0.040)* [0.15]*	-0.70 (0.041)* [0.15]*	-0.43 (0.013)*	-0.43 (0.016)*	-0.41 (0.035)* [0.13]*	-0.35 (0.035)* [0.12]*	-0.31 (0.011)*	-0.31 (0.0085)*
ln(CDD)	-	-0.017 (0.023) [0.018]	-	0.0082 (0.0015)*	-	-0.0032 (0.018) [0.016]	-	0.0086 (0.00093)*
ln(HDD)	-	0.073 (0.046) [0.041]***	-	0.059 (0.0034)*	-	0.078 (0.036)** [0.034]**	-	0.056 (0.0020)*
coal production	-	4.17x10 ⁻⁶ (3.73x10 ⁻⁷)* [1.04x10 ⁻⁶]*	-	1.45x10 ⁻⁶ (9.03x10 ⁻⁸)*	-	2.44x10 ⁻⁶ (2.34x10 ⁻⁷)* [4.08x10 ⁻⁷]*	-	9.27x10 ⁻⁷ (5.14x10 ⁻⁸)*
income at emissions peak (1999\$)	\$14,708 (\$801) [\$2,364]	\$16,157 (\$996) [\$2,812]	\$16,449 (\$336)	\$16,840 (\$354)	\$20,389 (\$1,717) [\$5,694]	\$23,870 (\$2,556) [\$8,117]	\$22,072 (\$481)	\$21,491 (\$428)

N = 1,920.

Robust standard errors presented in parentheses and robust standard errors clustered by state in brackets for OLS specifications.

Standard errors corrected for first-order serial correlation and for heteroskedasticity for FGLS specifications.

*, **, *** statistically significant at 1, 5, 10 percent levels.

Regressions also include a constant term, state and year fixed effects.

Table 3. Test Statistics Comparing Production- and Consumption-Based CO₂ Environmental Kuznets Curves

	(1)	(2)
Specification	OLS	OLS
State and Year Effects	Yes	Yes
X Vector	No	Yes
F-Statistic, H_0^1	112.54	86.70
F-Statistic, H_0^2	47.50	40.52

N = 1,920

Based on a bivariate regressions in which the dependent variables are $\ln(\text{CO}_2)$ and $\ln(\text{CO}_2^{\text{cons}})$. The errors in these regressions are assumed to be homoskedastic.

Table 4. Summary Statistics for the Heterogeneous Slopes Regression Models

Dependent Variable	ln(CO ₂)	ln(CO ₂ ^{cons})
Number of states with inverted-U income-emissions relationship	44	40
Number of states with statistically significant estimated EKC peaks	40	37
Mean EKC peak for states with inverted-U relationships	\$14,952	\$14,611 [†]
Median EKC peak for states with inverted-U relationships	\$15,844	\$18,231
F-Statistic, H_0^3	53.78	54.52
F-Statistic, H_0^4	56.45	52.43

Notes: Regressions specified as quadratic income, and includes state and year fixed effects. These regressions were estimated with robust standard errors.

[†] The mean excludes two states with an estimated per capita income at the EKC peak in excess of \$1,000,000.

Table 5. State-Specific Regressions, Standard/Production-Based Carbon Dioxide Emissions

State	OLS				DOLS		
	ln(y)	(lny) ²	EKC Peak	EG-ADF Statistic	ln(y)	(lny) ²	EKC Peak
Alabama	12.29 (5.21)**	-0.63 (0.27)**	\$18,439 (\$2,338)*	-3.137***	16.88 (18.22)	-0.85 (0.92)	\$19,937 (\$3,506)*
Arizona	29.29 (9.05)*	-1.48 (0.46)*	\$19,906 (\$1,184)*	-1.890	42.35 (12.76)*	-2.16 (0.66)*	\$18,056 (\$973)*
Arkansas	2.34 (3.72)	-0.095 (0.20)	\$218,575 (\$1,280,016)	-2.360	1.18 (5.60)	-0.042 (0.29)	\$1,424,092 (\$43,200,000)
California	65.23 (10.76)*	-3.28 (0.54)*	\$20,490 (\$328)*	-3.405**	90.43 (14.59)*	-4.55 (0.72)*	\$20,553 (\$719)*
Colorado	16.45 (3.07)*	-0.82 (0.16)*	\$22,281 (\$651)*	-2.059	22.72 (4.50)*	-1.14 (0.23)*	\$20,356 (\$1,198)*
Connecticut	7.59 (9.16)	-0.39 (0.45)	\$15,101 (\$9,133)	-2.452	-3.45 (15.38)	0.13 (0.75)	NA
Delaware	37.44 (4.55)*	-1.88 (0.23)*	\$21,460 (\$263)*	-3.987*	40.92 (7.78)*	-2.04 (0.38)*	\$22,202 (\$708)*
Florida	19.54 (3.81)*	-0.98 (0.20)*	\$20,278 (\$681)*	-2.814	20.55 (5.20)*	-1.04 (0.26)*	\$18,639 (\$542)*
Georgia	23.02 (2.76)*	-1.15 (0.14)*	\$22,770 (\$863)*	-2.318	25.54 (2.41)*	-1.28 (0.12)*	\$20,810 (\$785)*
Idaho	13.62 (13.95)	-0.72 (0.72)	\$13,538 (\$2,276)*	-2.138	41.04 (22.84)***	-2.09 (1.16)**	\$18,581 (\$2,586)*
Illinois	26.98 (9.70)*	-1.36 (0.49)*	\$20,469 (\$645)*	-1.414	14.10 (17.68)	-0.76 (0.88)	\$10,571 (\$9,873)

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Indiana	5.38 (2.98)***	-0.25 (0.15)	\$47,503 (\$28,380)	-2.613	2.65 (6.71)	-0.11 (0.34)	\$101,112 (\$480,480)
Iowa	-7.84 (2.89)*	0.44 (0.15)*	NA	-2.640	-12.72 (6.28)***	0.68 (0.32)**	NA
Kansas	20.24 (3.17)*	-1.00 (0.16)*	\$25,193 (\$1,260)*	-3.743**	23.18 (3.10)*	-1.15 (0.16)*	\$23,120 (\$1,756)*
Kentucky	5.81 (4.47)	-0.26 (0.23)	\$82,085 (\$127,704)	-2.288	4.97 (8.36)	-0.21 (0.43)	\$125,080 (\$503,219)
Louisiana	29.78 (5.26)*	-1.51 (0.27)*	\$18,804 (\$811)*	-3.065***	28.81 (4.63)*	-1.49 (0.24)*	\$16,172 (\$770)*
Maine	16.34 (9.96)	-0.84 (0.51)	\$16,618 (\$738)*	-2.456	23.98 (20.23)	-1.23 (1.03)	\$16,963 (\$3,191)*
Maryland	14.22 (6.13)**	-0.72 (0.31)**	\$18,509 (\$1,133)*	-2.306	19.39 (9.45)***	-0.98 (0.47)**	\$20,514 (\$2,477)*
Massachusetts	20.00 (5.08)*	-1.00 (0.25)*	\$21,616 (\$471)*	-2.778	10.34 (9.14)	-0.53 (0.45)	\$17,950 (\$5,281)*
Michigan	17.84 (6.61)*	-0.89 (0.34)**	\$21,762 (\$1,183)*	-1.494	-3.23 (14.62)	0.15 (0.73)	NA
Minnesota	5.42 (4.73)	-0.26 (0.24)	\$38,146 (\$24,753)	-2.252	1.81 (9.67)	-0.087 (0.49)	\$33,535 (\$95,866)
Mississippi	14.78 (3.67)*	-0.75 (0.20)*	\$18,942 (\$2,485)*	-1.381	14.17 (6.89)**	-0.74 (0.36)**	\$14,224 (\$1,703)*
Missouri	28.13 (6.20)*	-1.40 (0.32)*	\$23,080 (\$1,577)*	-2.917***	23.79 (10.51)**	-1.21 (0.53)**	\$18,552 (\$1,421)*
Montana	-45.79 (13.22)*	2.44 (0.68)*	NA	-2.437	-78.83 (30.30)**	4.17 (1.55)**	NA

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Nebraska	3.03 (4.41)	-0.12 (0.23)	\$204,403 (\$931,062)	-1.954	4.47 (6.90)	-0.21 (0.35)	\$46,793 (\$74,477)
Nevada	119.01 (19.65)*	-5.90 (0.98)*	\$23,942 (\$412)*	-2.798	170.32 (29.72)*	-8.49 (1.50)*	\$22,638 (\$617)*
New Hampshire	19.90 (7.51)**	-0.99 (0.38)**	\$22,315 (\$1,675)*	-2.695	12.91 (9.34)	-0.67 (0.47)	\$14,971 (\$4,107)*
New Jersey	12.57 (4.21)*	-0.62 (0.21)*	\$24,888 (\$850)*	-2.552	8.43 (5.18)	-0.42 (0.26)	\$24,363 (\$3,022)*
New Mexico	46.81 (7.39)*	-2.40 (0.38)*	\$17,083 (\$427)*	-2.464	48.52 (4.67)*	-2.48 (0.24)*	\$17,356 (\$860)*
New York	20.28 (10.87)***	-1.02 (0.54)***	\$19,881 (\$1,684)*	-2.384	5.32 (20.89)	-0.30 (1.03)	\$6,872 (\$31,432)
North Carolina	18.20 (3.64)*	-0.92 (0.19)*	\$18,871 (\$1,160)*	-2.144	13.76 (8.57)	-0.72 (0.43)	\$14,800 (\$3,222)*
North Dakota	-22.24 (17.61)	1.25 (0.92)	NA	-1.918	-92.99 (34.70)**	4.87 (1.77)**	NA
Ohio	27.84 (6.34)*	-1.41 (0.32)*	\$19,560 (\$350)*	-2.062	22.47 (13.91)	-1.16 (0.70)	\$16,762 (\$2,458)*
Oklahoma	9.33 (4.56)**	-0.45 (0.23)***	\$34,006 (\$12,535)*	-3.653**	3.35 (4.92)	-0.12 (0.25)	\$731,792 (\$5,503,106)
Oregon	1.89 (11.74)	-0.083 (0.60)	\$86,769 (\$970,965)	-1.894	10.40 (17.47)	-0.51 (0.88)	\$24,918 (\$15,071)
Pennsylvania	21.38 (5.32)*	-1.09 (0.27)*	\$17,958 (\$453)*	-2.263	13.78 (13.34)	-0.72 (0.67)	\$15,210 (\$5,702)**
Rhode Island	-22.96 (9.26)**	1.14 (0.47)**	NA	-2.018	-57.54 (15.12)*	2.85 (0.76)*	NA

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South Carolina	5.59 (1.90)*	-0.27 (0.10)**	\$33,490 (\$11,098)*	-2.609	3.27 (3.62)	-0.16 (0.18)	\$33,732 (\$28,255)
South Dakota	5.84 (6.10)	-0.27 (0.31)	\$40,279 (\$42,399)	-2.811	12.99 (7.89)	-0.66 (0.41)	\$19,692 (\$4,698)*
Tennessee	9.56 (2.06)*	-0.48 (0.11)*	\$21,201 (\$1,486)*	-3.646**	5.57 (4.51)	-0.29 (0.23)	\$16,451 (\$4,860)*
Texas	18.49 (3.57)*	-0.93 (0.18)*	\$20,525 (\$944)*	-2.590	21.14 (2.68)*	-1.08 (0.14)*	\$17,556 (\$872)*
Utah	-19.18 (8.88)**	1.02 (0.46)**	NA	-2.119	-33.00 (16.35)***	1.76 (0.86)**	NA
Vermont	1.23 (6.57)	-0.060 (0.34)	\$26,993 (\$74,144)	-2.154	-5.92 (11.53)	0.29 (0.59)	NA
Virginia	6.81 (4.13)	-0.36 (0.21)***	\$14,109 (\$2,222)*	-2.311	4.47 (11.89)	-0.24 (0.59)	\$9,045 (\$20,738)
Washington	17.50 (7.16)**	-0.85 (0.36)**	\$30,363 (\$5,295)*	-1.969	16.15 (16.11)	-0.79 (0.81)	\$28,835 (\$10,217)*
West Virginia	26.04 (3.29)*	-1.32 (0.17)*	\$19,176 (\$858)*	-3.994*	25.34 (6.01)*	-1.29 (0.30)*	\$18,429 (\$1,314)*
Wisconsin	-0.41 (8.06)	0.037 (0.41)	NA	-1.370	-7.40 (12.99)	0.36 (0.65)	NA
Wyoming	13.24 (17.82)	-0.56 (0.91)	\$130,405 (\$416,196)	-1.649	9.68 (31.98)	-0.40 (1.65)	\$198,552 (\$2,095,308)

Newey-West standard errors presented in parentheses.

*, **, *** statistically significant at 1, 5, 10 percent levels.

The critical values for the EG-ADF statistics are -3.77 ($p < 0.01$), -3.17 ($p < 0.05$), and -2.84 ($p < 0.10$) based on Engle and Granger (1987).

Table 6. State-Specific Regressions, Consumption-Based Carbon Dioxide Emissions

State	OLS				DOLS		
	ln(y)	(lny) ²	EKC Peak	EG-ADF Statistic	ln(y)	(lny) ²	EKC Peak
Alabama	17.56 (5.96)*	-0.90 (0.31)*	\$16,567 (\$972)*	-1.904	32.04 (18.67)***	-1.62 (0.94)***	\$18,813 (\$2,058)*
Arizona	45.75 (6.94)*	-2.34 (0.36)*	\$17,529 (\$285)*	-3.122***	62.94 (6.94)*	-3.24 (0.36)*	\$16,562 (\$298)*
Arkansas	12.19 (5.33)**	-0.62 (0.28)**	\$18,119 (\$3,093)*	-1.512	9.31 (11.84)	-0.50 (0.61)	\$12,032 (\$5,847)**
California	50.42 (9.77)*	-2.52 (0.49)*	\$21,670 (\$311)*	-2.899***	75.01 (15.01)*	-3.76 (0.74)*	\$21,378 (\$746)*
Colorado	15.00 (3.18)*	-0.74 (0.16)*	\$23,568 (\$1,079)*	-2.248	21.06 (4.04)*	-1.06 (0.21)*	\$20,752 (\$1,374)*
Connecticut	-2.49 (11.32)	0.11 (0.56)	NA	-2.687	-15.31 (20.63)	0.72 (1.01)	NA
Delaware	12.85 (5.92)**	-0.64 (0.30)**	\$22,856 (\$591)*	-2.746	-4.48 (12.26)	0.21 (0.61)	NA
Florida	14.66 (2.55)*	-0.73 (0.13)*	\$23,202 (\$1,151)*	-3.072***	13.94 (3.87)*	-0.70 (0.20)*	\$21,809 (\$1,018)*
Georgia	22.22 (1.95)*	-1.11 (0.10)*	\$21,980 (\$588)*	-2.359	21.07 (1.63)*	-1.07 (0.082)*	\$19,384 (\$535)*
Idaho	17.28 (10.36)	-0.87 (0.54)	\$20,740 (\$3,594)*	-2.171	22.65 (15.72)	-1.13 (0.81)	\$22,830 (\$6,340)*
Illinois	33.32 (10.33)*	-1.68 (0.52)*	\$20,521 (\$534)*	-1.442	22.56 (17.16)	-1.19 (0.85)	\$13,034 (\$5,802)**

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Indiana	17.95 (3.52)*	-0.89 (0.18)*	\$23,683 (\$1,315)*	-2.231	19.10 (8.75)**	-0.95 (0.44)**	\$22,121 (\$1,466)*
Iowa	-0.52 (2.44)	0.069 (0.12)	NA	-2.640	-1.49 (6.07)	0.11 (0.31)	NA
Kansas	28.74 (3.62)*	-1.44 (0.18)*	\$21,763 (\$497)*	-3.058***	33.09 (2.80)*	-1.67 (0.14)*	\$19,880 (\$1,177)*
Kentucky	-2.71 (3.37)	0.18 (0.18)	NA	-2.489	-5.72 (7.11)	0.32 (0.36)	NA
Louisiana	29.69 (4.88)*	-1.50 (0.25)*	\$19,220 (\$843)*	-2.594	29.32 (4.41)*	-1.51 (0.22)*	\$16,866 (\$771)*
Maine	8.00 (10.56)	-0.40 (0.55)	\$19,898 (\$6,350)*	-2.189	10.81 (22.53)	-0.55 (1.14)	\$17,199 (\$7,079)**
Maryland	8.81 (4.71)***	-0.44 (0.24)***	\$21,302 (\$998)*	-2.531	14.01 (7.66)***	-0.69 (0.38)***	\$25,023 (\$2,721)*
Massachusetts	9.41 (4.49)**	-0.46 (0.22)**	\$28,217 (\$3,548)*	-2.334	4.60 (7.80)	-0.23 (0.39)	\$23,053 (\$5,717)*
Michigan	15.44 (7.55)**	-0.77 (0.38)***	\$22,198 (\$1,868)*	-1.523	-1.74 (15.12)	0.072 (0.76)	NA
Minnesota	9.47 (3.68)**	-0.46 (0.19)**	\$30,324 (\$5,991)*	-1.565	8.79 (6.86)	-0.43 (0.34)	\$24,952 (\$5,730)*
Mississippi	14.88 (2.74)*	-0.75 (0.15)*	\$19,374 (\$1,957)*	-1.612	13.73 (4.85)*	-0.71 (0.25)*	\$15,053 (\$1,220)*
Missouri	26.62 (4.79)*	-1.33 (0.24)*	\$22,771 (\$1,155)*	-2.071	22.60 (8.87)**	-1.14 (0.45)**	\$19,267 (\$1,174)*
Montana	-4.82 (9.00)	0.29 (0.46)	NA	-3.209**	-4.91 (18.72)	0.34 (0.96)	NA

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Nebraska	13.27 (5.76)**	-0.66 (0.30)**	\$24,550 (\$4,180)*	-2.152	17.20 (8.19)**	-0.87 (0.42)**	\$19,982 (\$1,652)*
Nevada	65.25 (11.72)*	-3.23 (0.58)*	\$24,588 (\$517)*	-1.815	81.92 (25.09)*	-4.07 (1.26)*	\$23,715 (\$1,276)*
New Hampshire	30.59 (5.68)*	-1.54 (0.29)*	\$21,189 (\$850)*	-2.341	33.84 (6.23)*	-1.72 (0.31)*	\$18,775 (\$755)*
New Jersey	13.25 (2.11)*	-0.64 (0.10)*	\$30,766 (\$1,596)*	-3.663**	6.14 (3.11)***	-0.29 (0.15)***	\$35,687 (\$6,462)*
New Mexico	14.72 (8.75)	-0.76 (0.46)	\$16,464 (\$1,202)*	-1.980	11.68 (6.61)***	-0.58 (0.35)	\$22,844 (\$9,817)**
New York	13.24 (11.81)	-0.67 (0.59)	\$20,067 (\$2,780)*	-2.688	-5.04 (22.22)	0.22 (1.09)	NA
North Carolina	16.43 (2.36)*	-0.83 (0.12)*	\$20,580 (\$1,072)*	-2.431	11.74 (6.06)***	-0.60 (0.31)***	\$16,976 (\$2,195)*
North Dakota	-29.34 (13.52)**	1.58 (0.70)**	NA	-2.046	-111.74 (34.14)*	5.81 (1.76)*	NA
Ohio	24.52 (5.65)*	-1.24 (0.29)*	\$19,867 (\$344)*	-2.269	20.64 (12.85)	-1.06 (0.65)	\$17,551 (\$2,127)*
Oklahoma	6.04 (4.69)	-0.28 (0.24)	\$50,517 (\$47,540)	-4.017*	-1.88 (4.21)	0.14 (0.21)	NA
Oregon	-1.36 (11.97)	0.073 (0.61)	NA	-1.988	-6.17 (17.56)	0.31 (0.89)	NA
Pennsylvania	25.87 (6.32)*	-1.33 (0.32)*	\$16,968 (\$597)*	-2.678	17.75 (15.16)	-0.93 (0.76)	\$14,067 (\$5,481)**
Rhode Island	-5.29 (4.24)	0.27 (0.22)	NA	-3.067***	-10.13 (11.12)	0.51 (0.56)	NA

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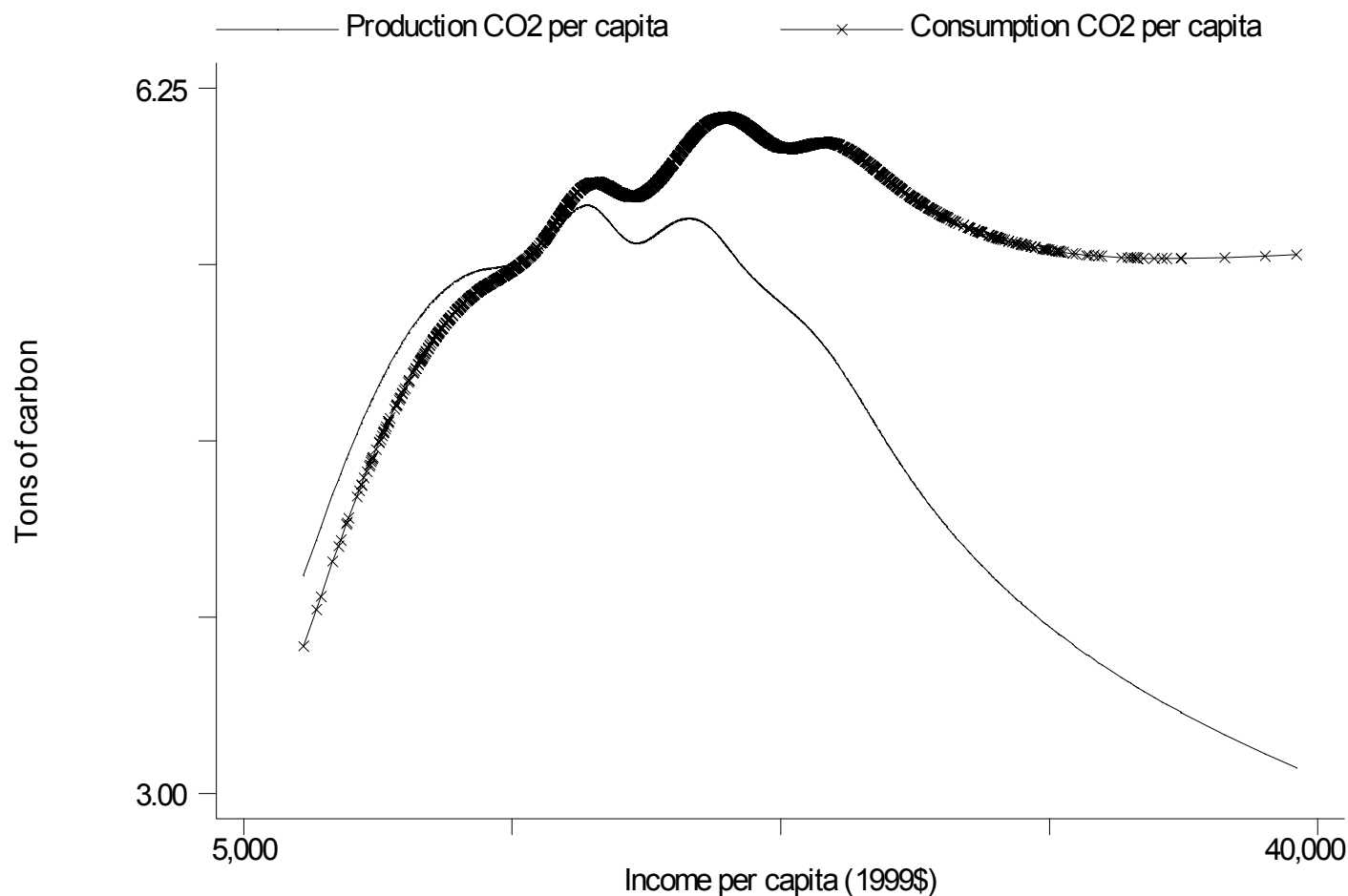
South Carolina	8.69 (2.39)*	-0.44 (0.13)*	\$19,190 (\$2,061)*	-3.956*	5.26 (4.33)	-0.27 (0.22)	\$14,452 (\$4,463)*
South Dakota	-0.63 (4.06)	0.058 (0.21)	NA	-3.358**	2.68 (6.35)	-0.12 (0.33)	\$112,247 (\$690,014)
Tennessee	15.67 (2.52)*	-0.80 (0.13)*	\$17,848 (\$455)*	-3.233**	14.78 (4.43)*	-0.76 (0.22)*	\$16,590 (\$2,007)*
Texas	18.39 (3.39)*	-0.92 (0.17)*	\$20,675 (\$937)*	-2.363	20.82 (2.75)*	-1.06 (0.14)*	\$17,884 (\$860)*
Utah	5.90 (6.79)	-0.31 (0.35)	\$14,517 (\$2,252)*	-1.822	24.60 (10.82)**	-1.30 (0.56)**	\$13,099 (\$1,783)*
Vermont	9.60 (11.58)	-0.50 (0.60)	\$14,654 (\$2,347)*	-2.213	-5.28 (18.39)	0.24 (0.94)	NA
Virginia	6.41 (2.74)**	-0.32 (0.14)**	\$23,522 (\$2,810)*	-2.774	9.45 (9.02)	-0.46 (0.45)	\$25,607 (\$2,872)*
Washington	14.96 (6.93)**	-0.72 (0.35)**	\$32,803 (\$7,709)*	-2.420	10.08 (16.22)	-0.48 (0.82)	\$40,116 (\$46,202)
West Virginia	32.04 (6.10)*	-1.68 (0.32)*	\$13,972 (\$251)*	-2.284	37.43 (5.92)*	-1.94 (0.30)*	\$15,816 (\$1,164)*
Wisconsin	-3.36 (7.24)	0.19 (0.37)	NA	-1.717	-10.67 (11.77)	0.54 (0.59)	NA
Wyoming	36.41 (9.17)*	-1.80 (0.47)*	\$24,572 (\$2,100)*	-1.971	25.85 (16.06)	-1.26 (0.83)	\$29,330 (\$11,702)**

Newey-West standard errors presented in parentheses.

*, **, *** statistically significant at 1, 5, 10 percent levels.

The critical values for the EG-ADF statistics are -3.77 ($p < 0.01$), -3.17 ($p < 0.05$), and -2.84 ($p < 0.10$) based on Engle and Granger (1987).

Figure 1. Production- and Consumption-based Carbon Dioxide Environmental Kuznets Curves from Cubic Spline Regressions



Notes: Functions derived from regressions of the natural logarithm of per capita emissions on a ten-knot cubic spline function of the natural logarithm of per capita income and state and year fixed effects. The knots are placed at equally-spaced quantiles. The figure presents the fitted values for the 1,920 income per capita observations in the data.